The “Deep Blue” aerosol project at NASA GSFC

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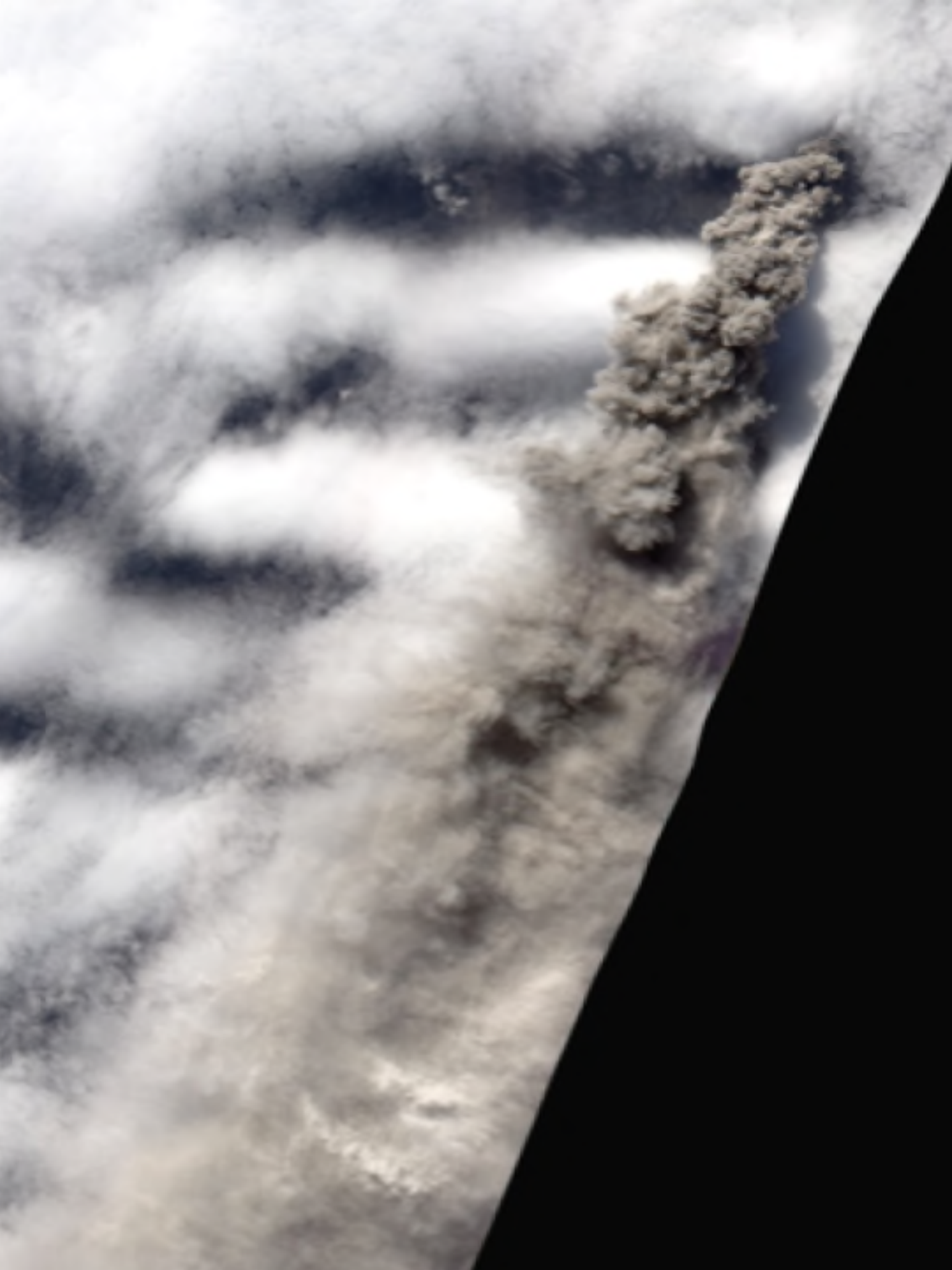
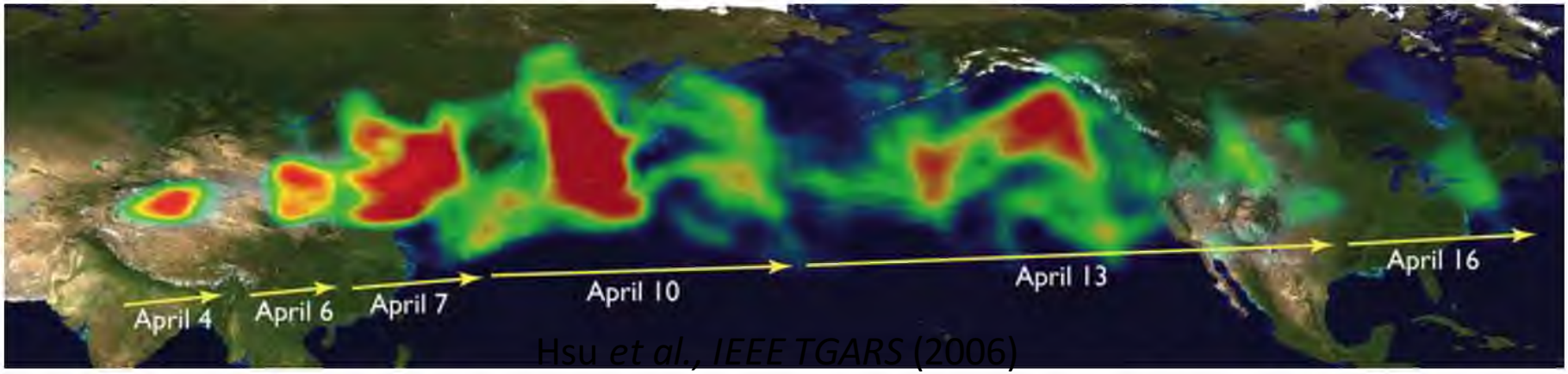
https://deepblue.gsfc.nasa.gov/

- Aerosols:
  - What, why, and how?
  - The Deep Blue aerosol data sets
- Current challenges and new directions
  - Calibration
  - Aerosols above clouds

Aerosols



Satellites give us the big picture

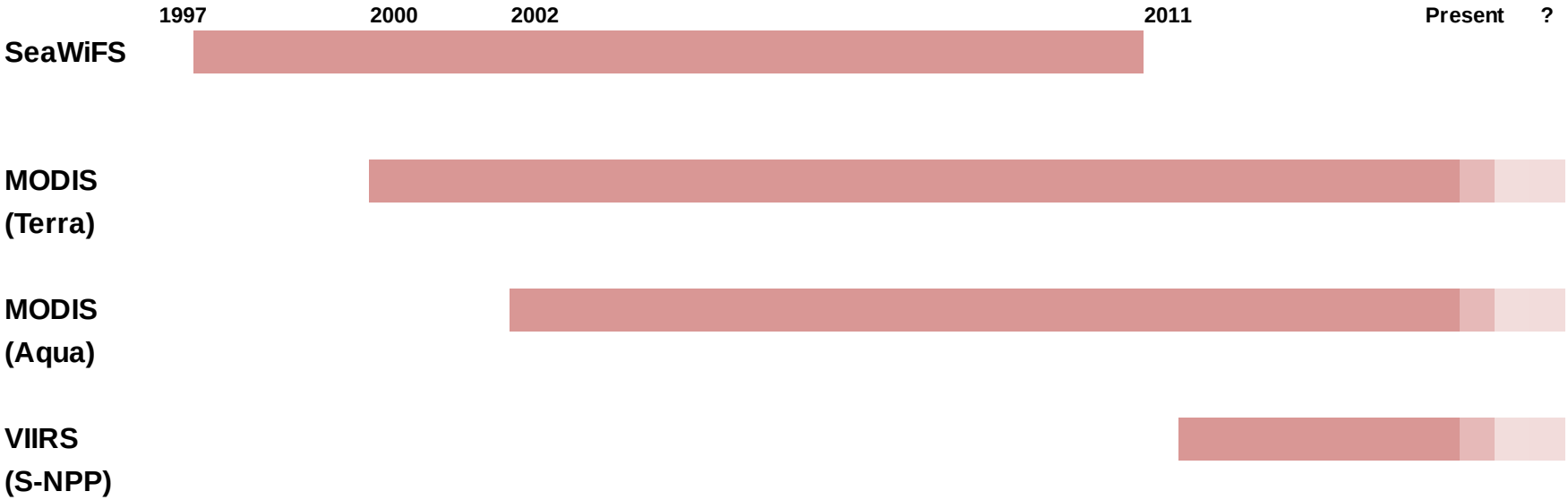


Hsu *et al.*, *IEEE TGARS* (2006)

Fig. 1. Time series of TOMS AI composite in April 2001 showing the long-range transport of Asian dust across the Pacific reaching as far as the east coast of the U.S.

Hsu *et al.*, IEEE TGARS (2006)

Using multiple similar satellite sensors helps to create a consistent long data record



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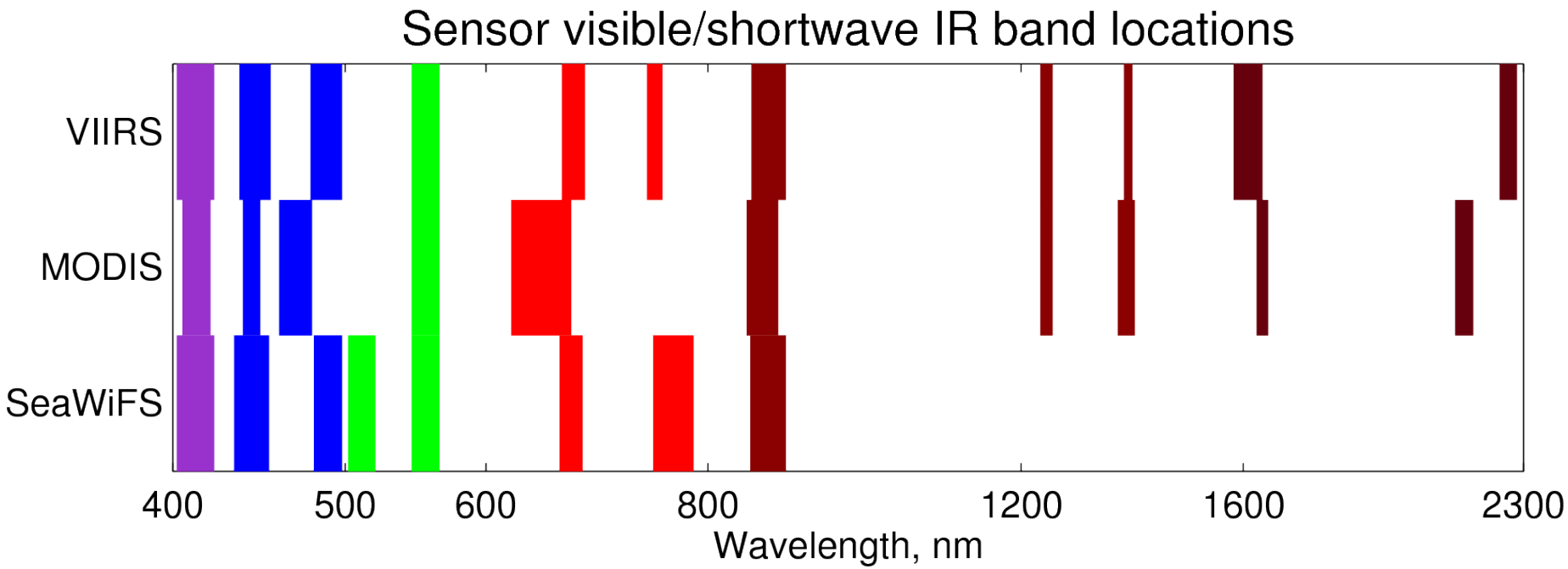

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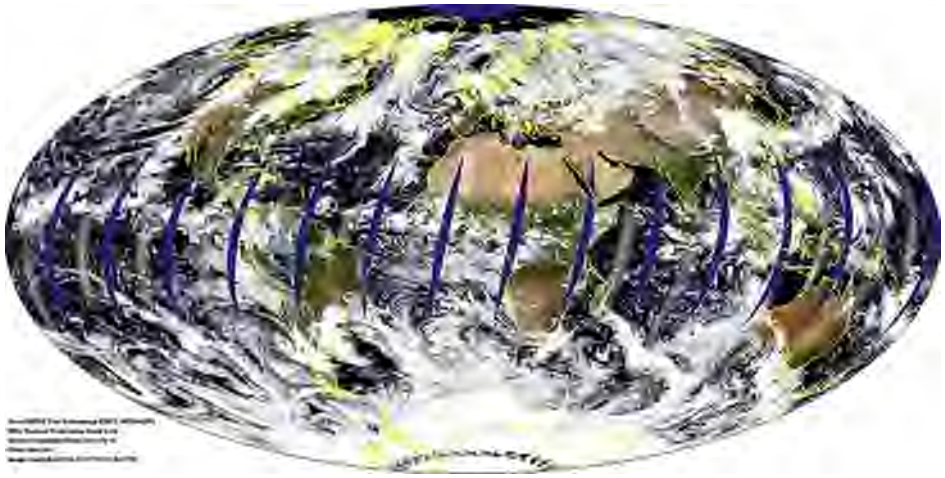
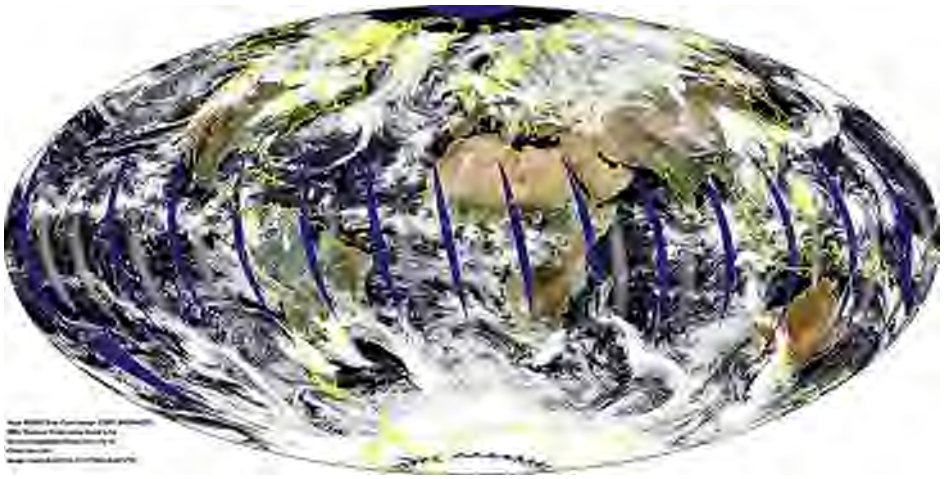


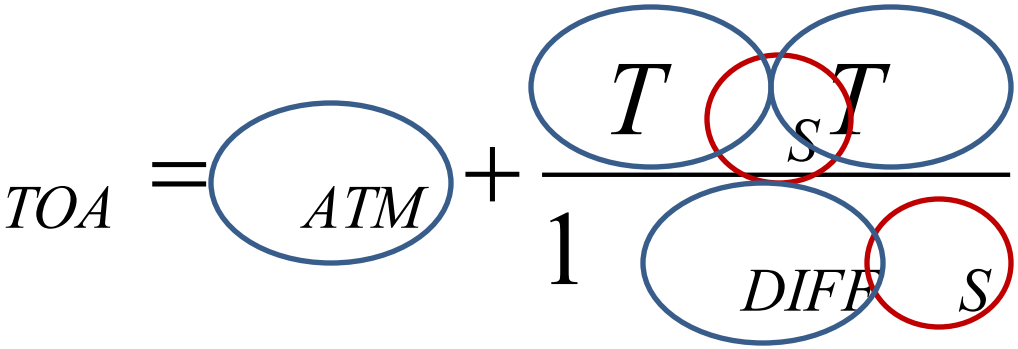
MODIS Terra
10:30 am/pm local solar Equatorial crossing time



MODIS Aqua
1:30 am/pm local solar Equatorial crossing time

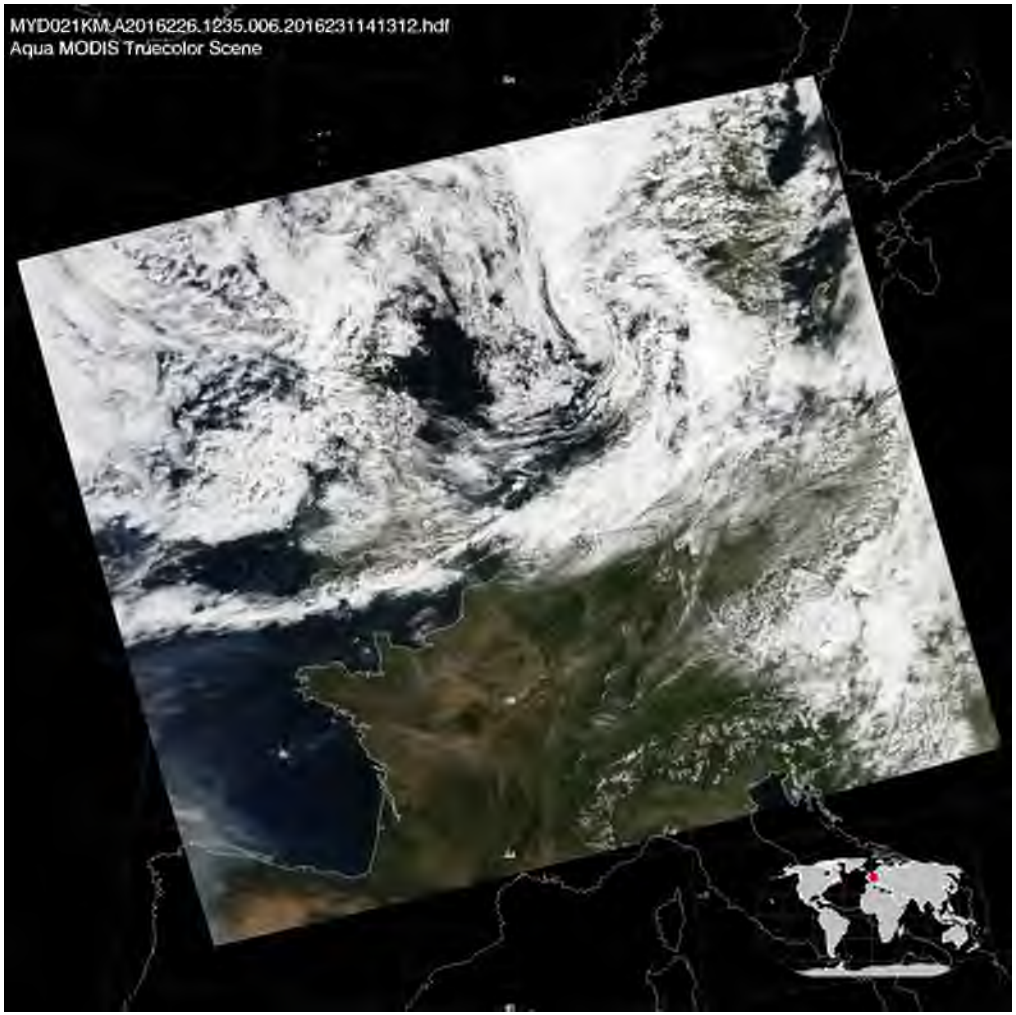
- Level 1 pixel sizes ~ 1 km or finer
- Level 2 pixel sizes ~ 5-15 km
- Daytime revisit ~ daily

Satellite aerosol remote sensing is a complex, underconstrained problem



- Atmosphere
  - Aerosols
  - Trace gases
  - Molecular (Rayleigh) scattering
- Surface reflectance
- All have spectral and directional dependence
- Need additional constraints as input beyond the satellite observations

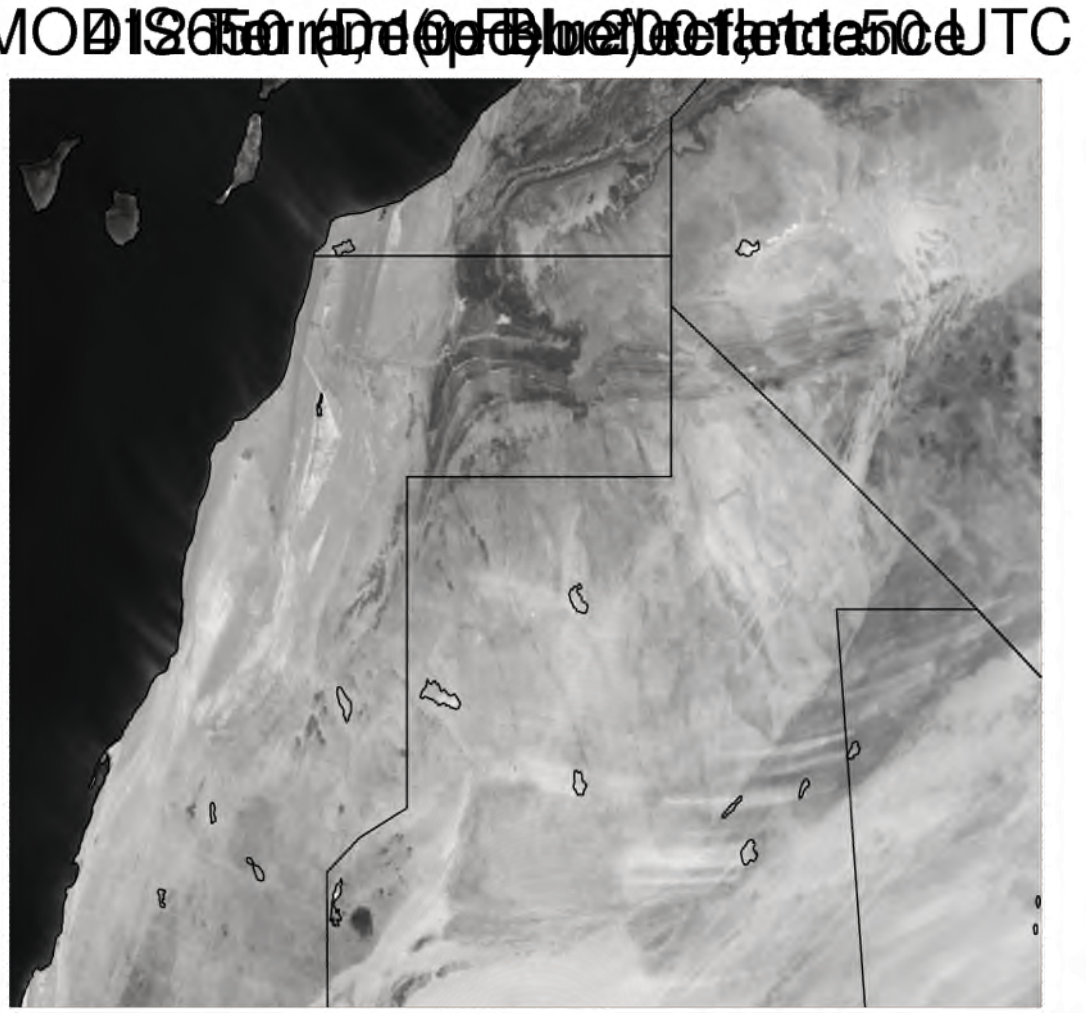
The aerosol signal is often small, and we cannot see through clouds



Surface cover changes through time, often rapidly

NASA Earth Observatory, http://earthobservatory.nasa.gov/Features/Aerosols/

Blue spectral bands offer high contrast between surface and atmospheric features



The main quantity we determine from space is aerosol optical depth (AOD, τ)

$$= \int_0 \left({}_{sca,} (z) + {}_{abs,} (z) \right) dz$$

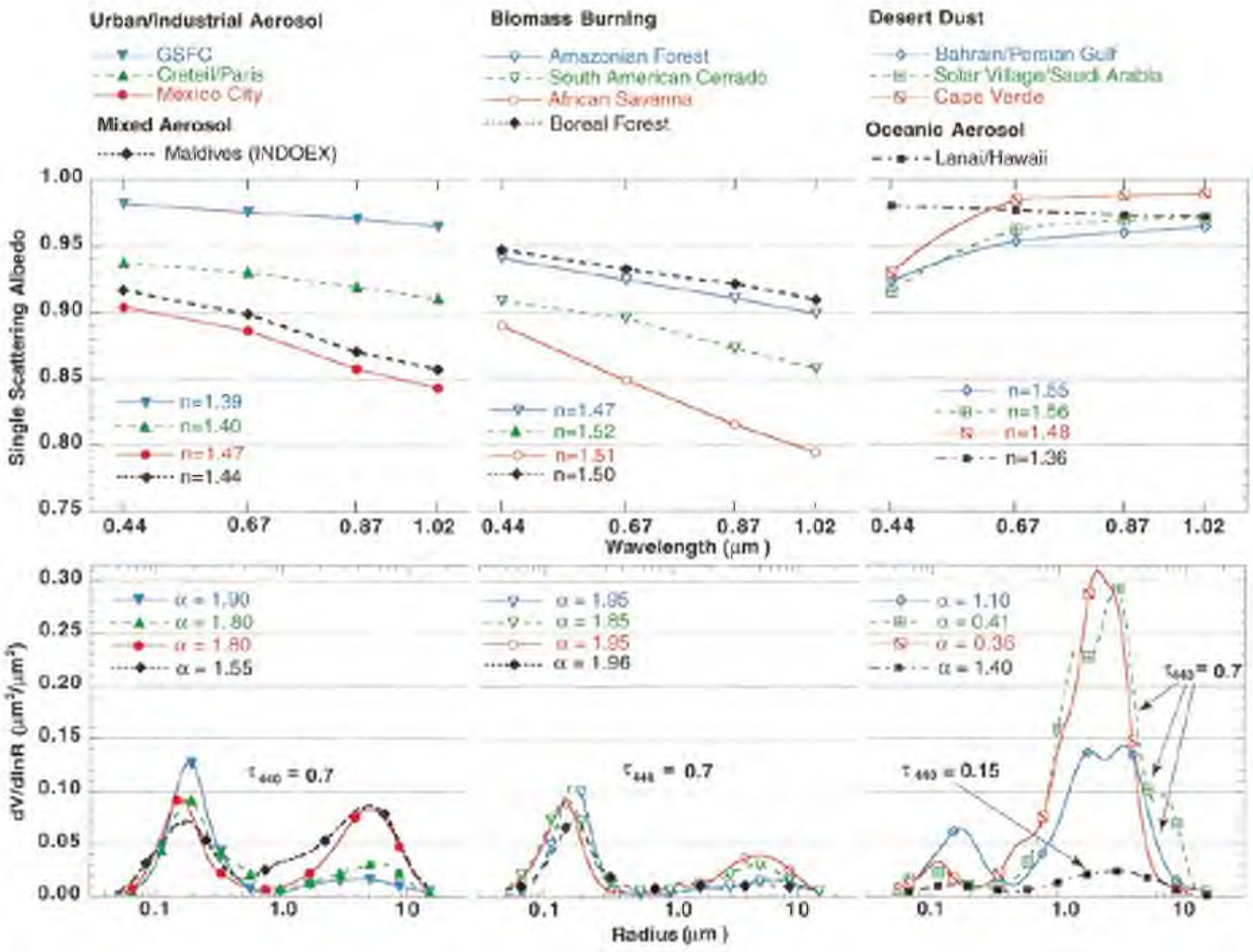
$$= \frac{d \log(\quad)}{d \log(\quad)} \qquad \frac{\log(\quad_2 / \quad_1)}{\log(\quad_2 / \quad_1)}$$

Ångström exponent (AE, !)

$${}_{0,} = \frac{{}_{sca,}}{{}_{sca,} + {}_{abs,}}$$

Single scattering albedo (SSA, " $_0$)

Aerosol scattering and absorption can be modeled using size distribution, shape, and refractive index



Dubovik *et al.*, JAS (2002)

The Deep Blue family consists of three separate AOD retrieval algorithms

Bright land

Surface reflectance database, BRDF correction

AOD retrieved separately at each of 412, 470/490, (650) nm

SSA retrieved for heavy dust events

Dark land

Spectral/directional surface reflectance relationship

AOD retrieved separately at 470/490 and 650 nm

Water

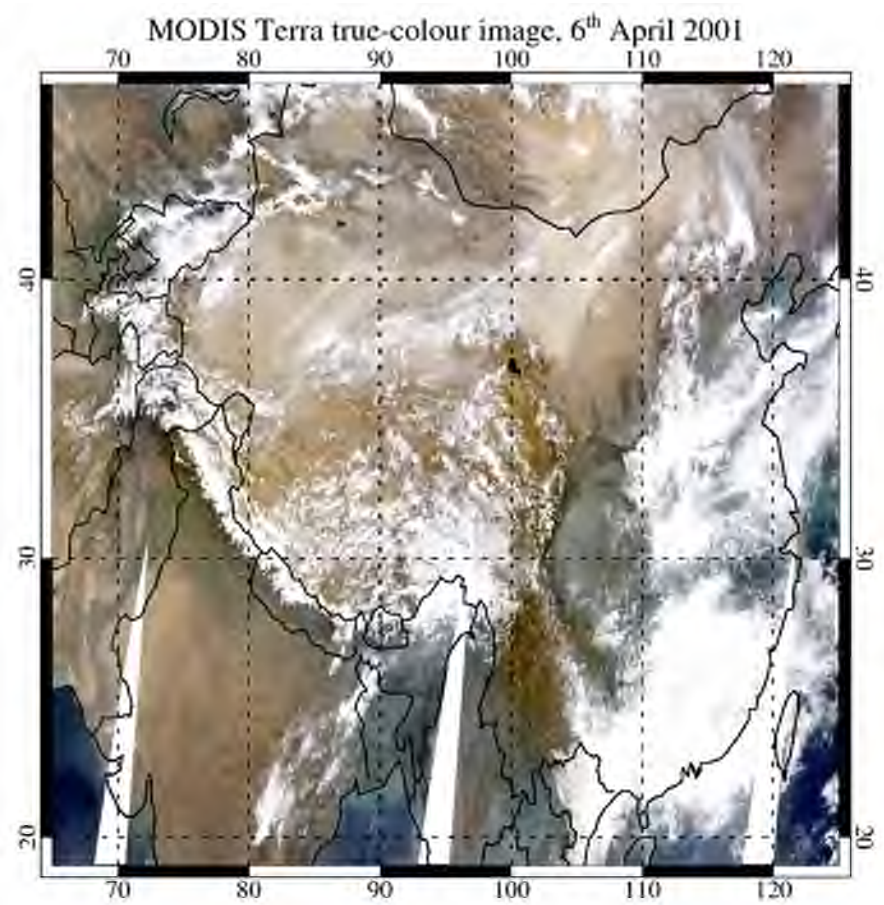
Surface BRDF including glint, foam, underlight

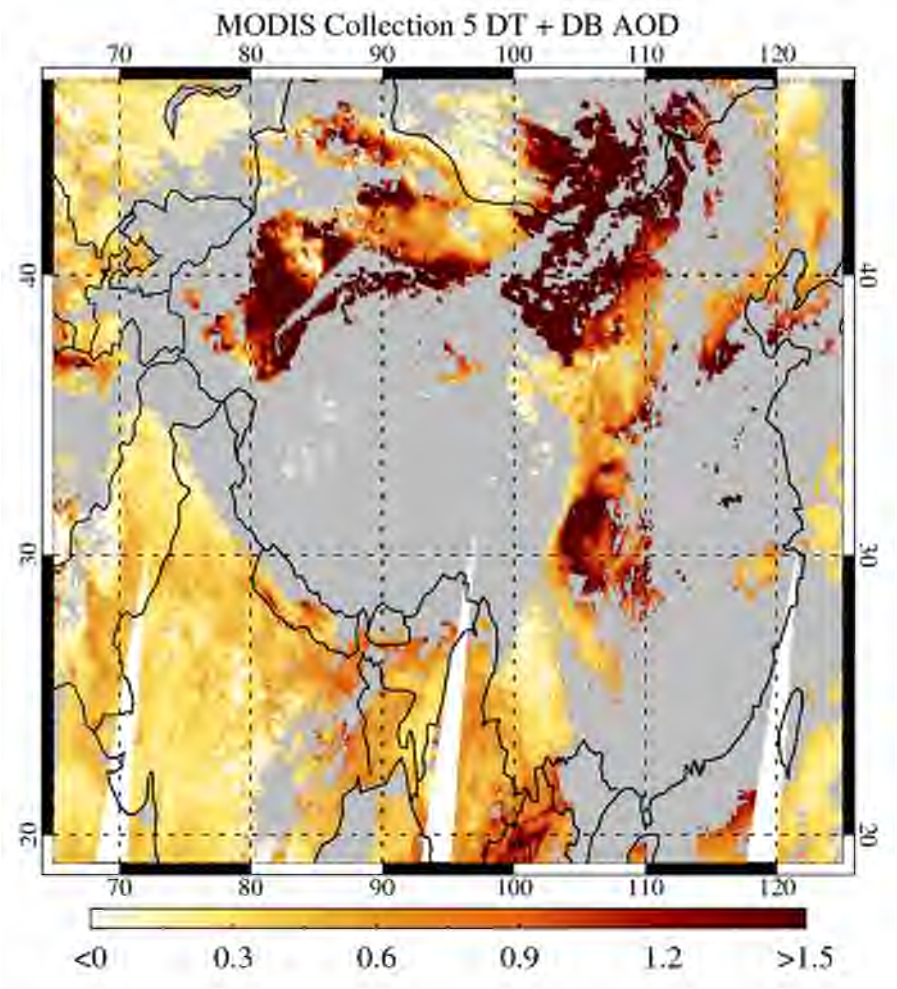
Multispectral inversion

(Not present in MODIS dataset)

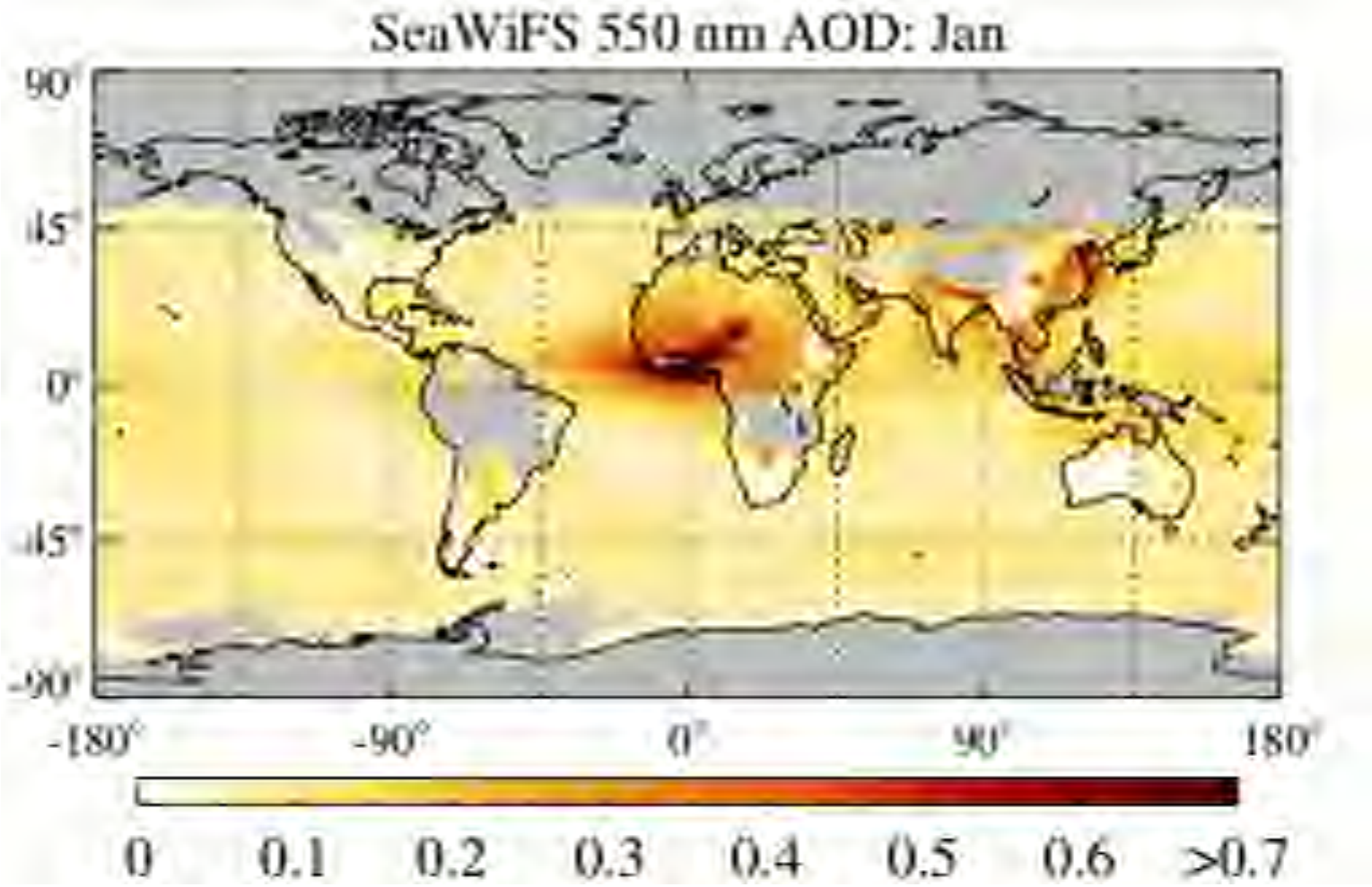
All report the AOD at 550 nm, and Ångström exponent (AE)

Deep Blue's initial contribution was to expand AOD coverage to bright surfaces

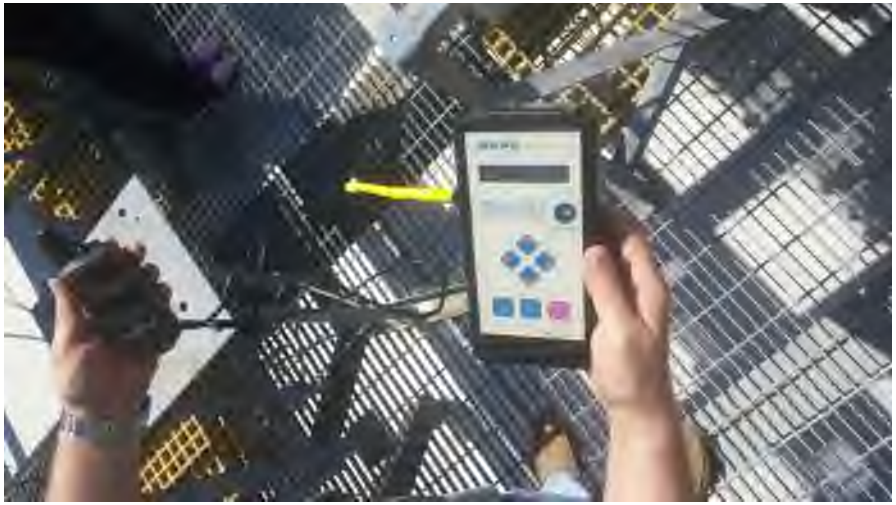




Coverage is near-global; clouds, snow, and polar night are unavoidable



Sun photometers provide our main validation data source



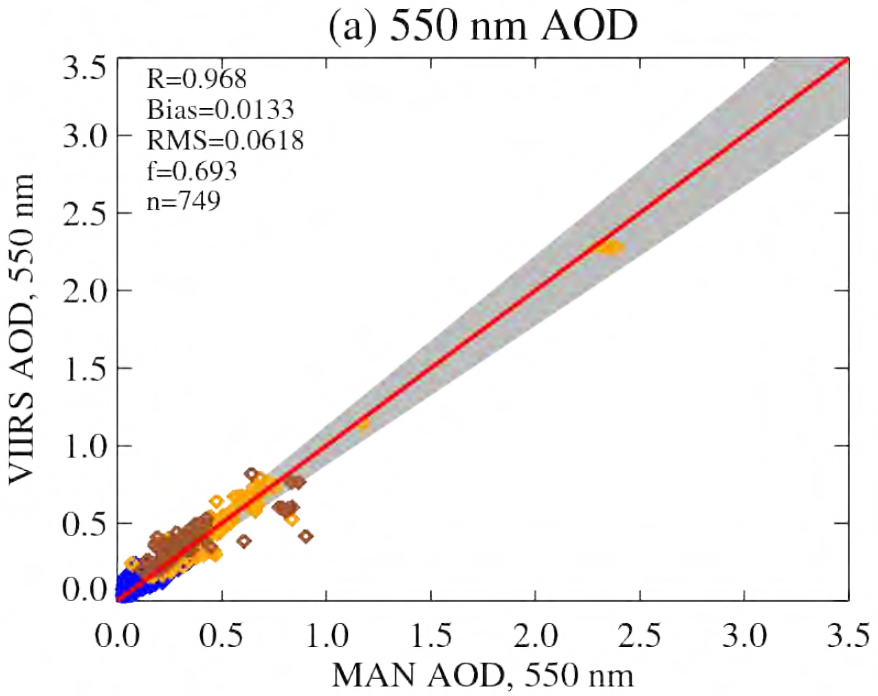
Hand-held Microtops Sun photometer
(credit B. Howl)

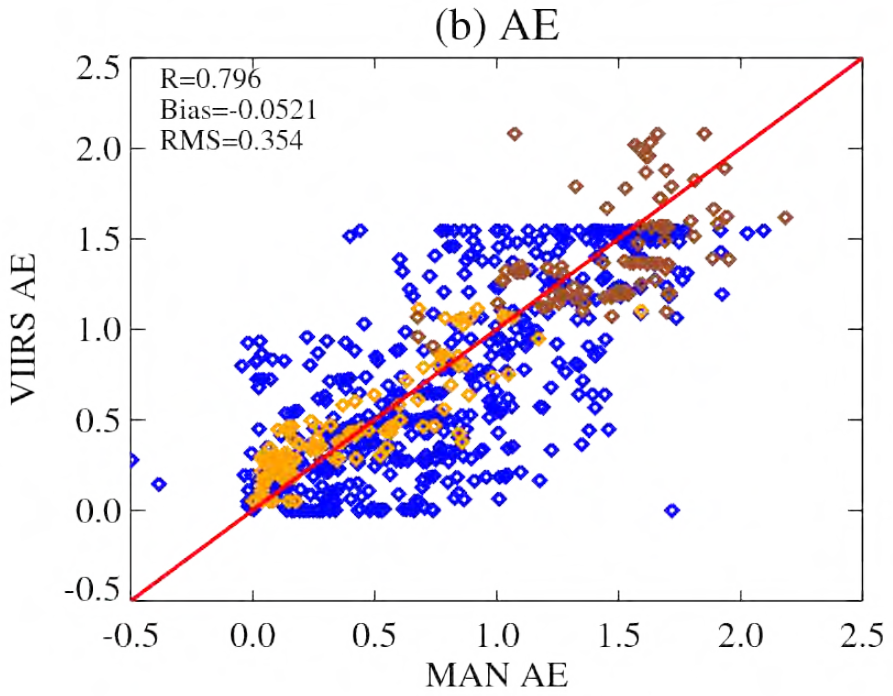
CIMEL CE-318 Sun photometer
(credit T. Yasunari, Hokkaido University, Japan)

Sun photometers provide our main validation data source

AERONET, aeronet.gsfc.nasa.gov

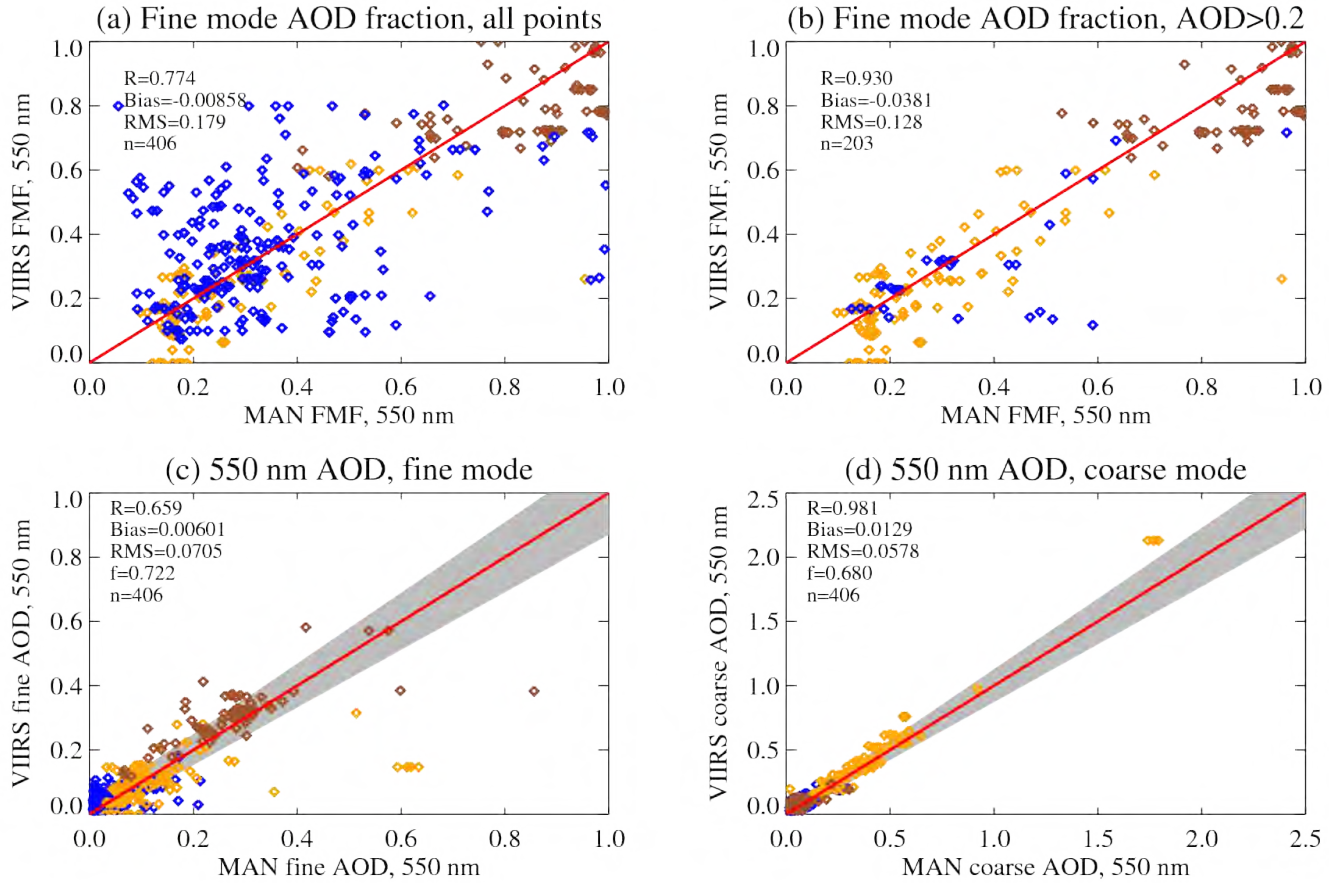
Validation helps us to quantify uncertainties and their contextual dependence





! Colours indicate aerosol optical model: **marine background**, **dust**, or **fine-mode dominated**

We can also examine more strongly-derived (as opposed to retrieved) quantities



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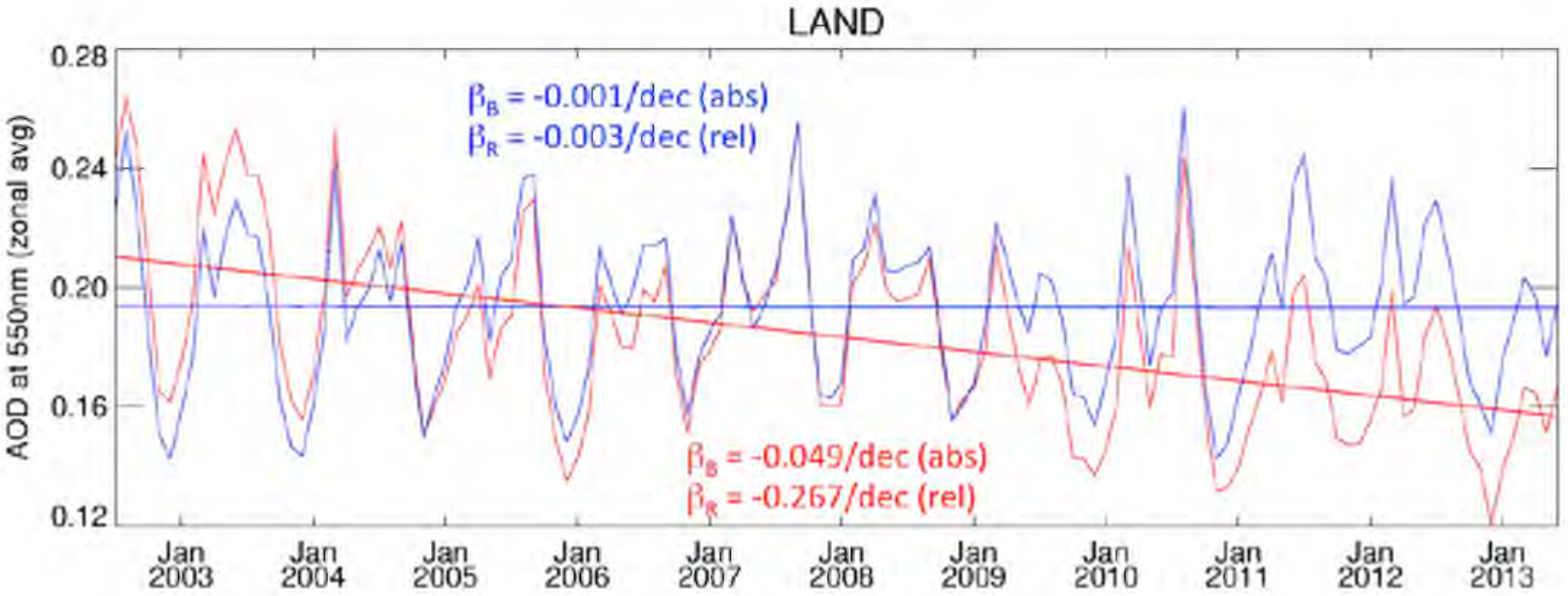
Current challenges and new directions

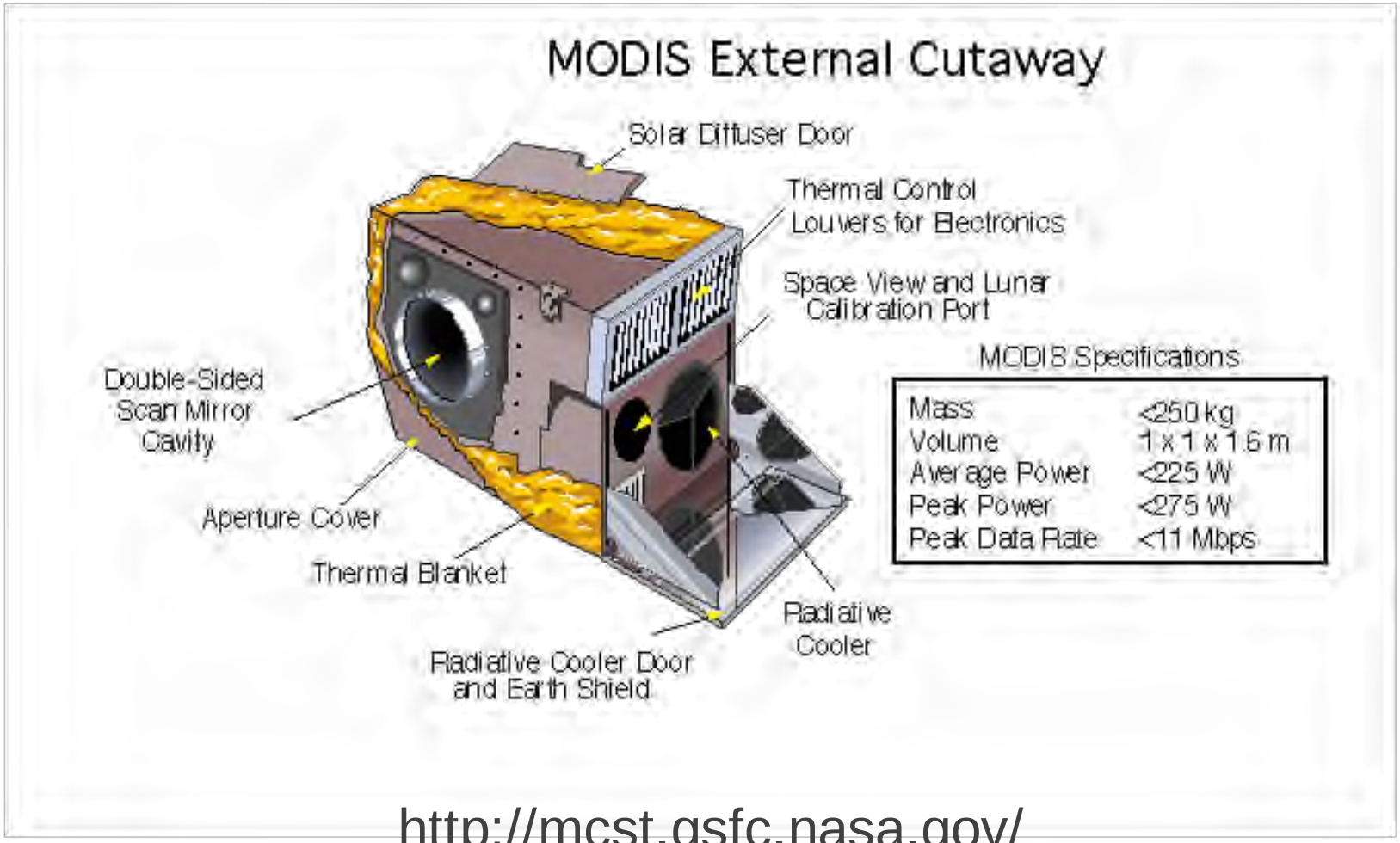
Calibration monitoring is necessary to ensure a stable, high-quality data set



MODIS Collection 5
Lyapustin *et al.*, AMT (2014)

Terra
Aqua

A lot of effort goes in to maintaining a high-quality sensor calibration



http://mcst.gsfc.nasa.gov/

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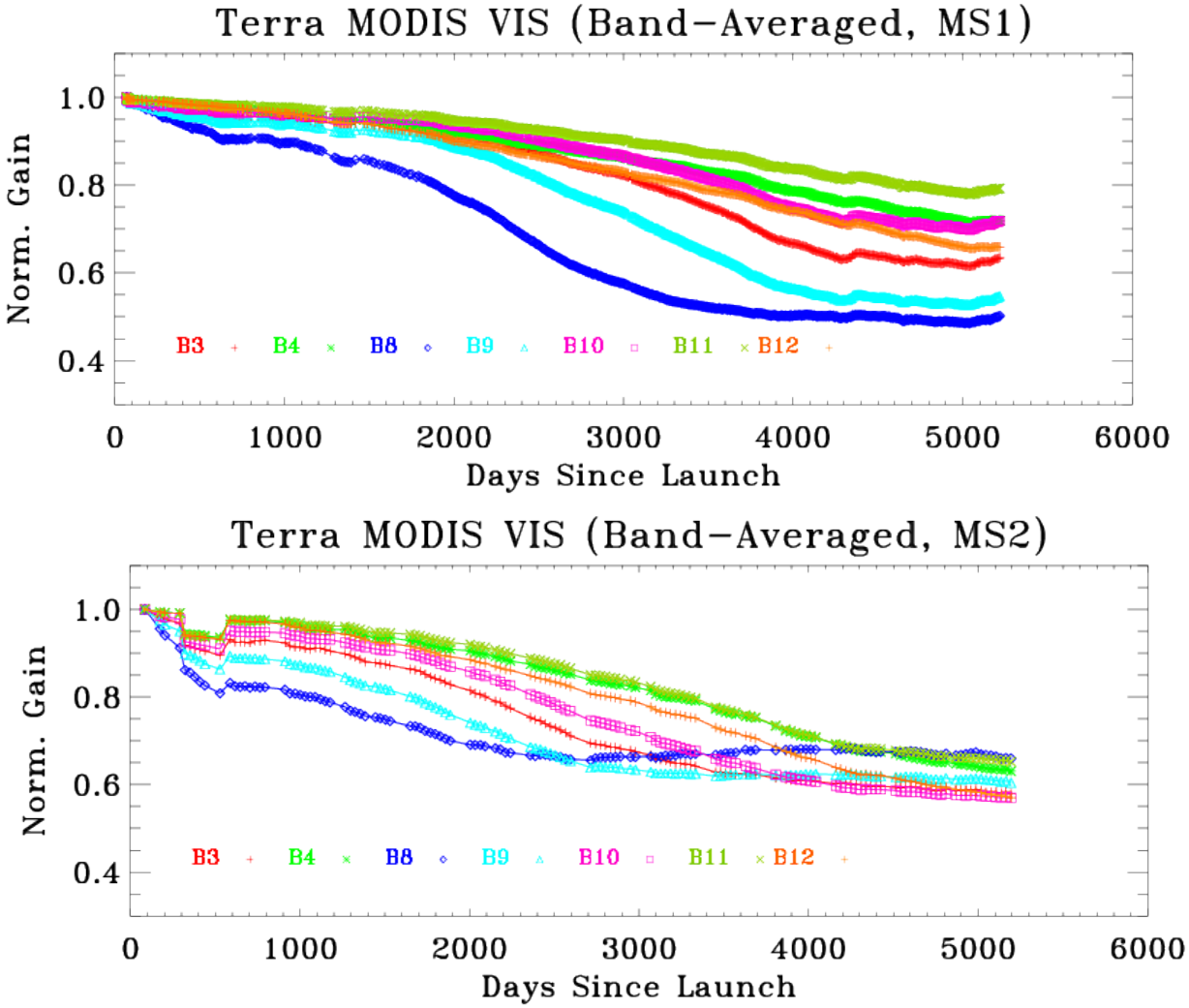
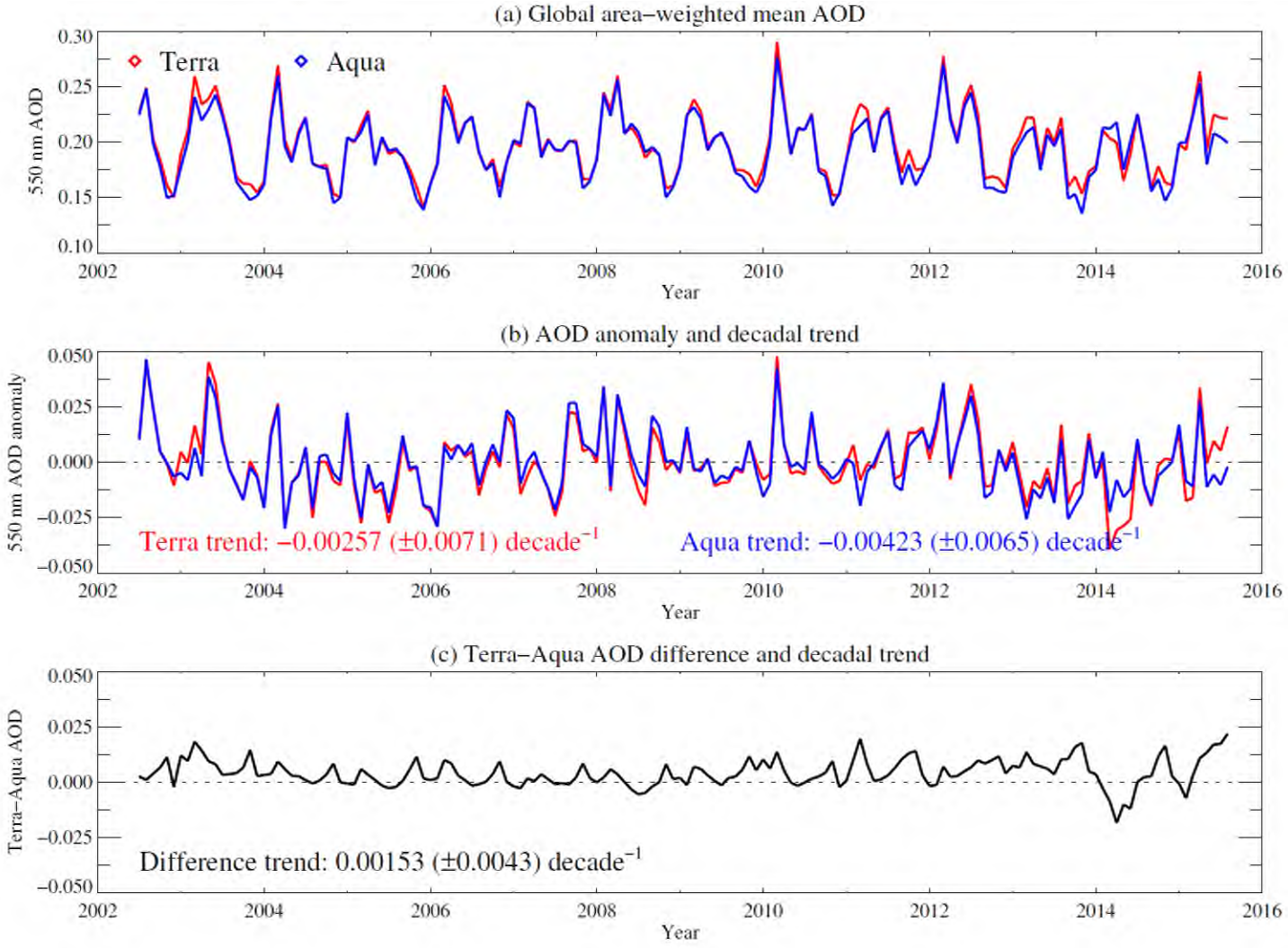
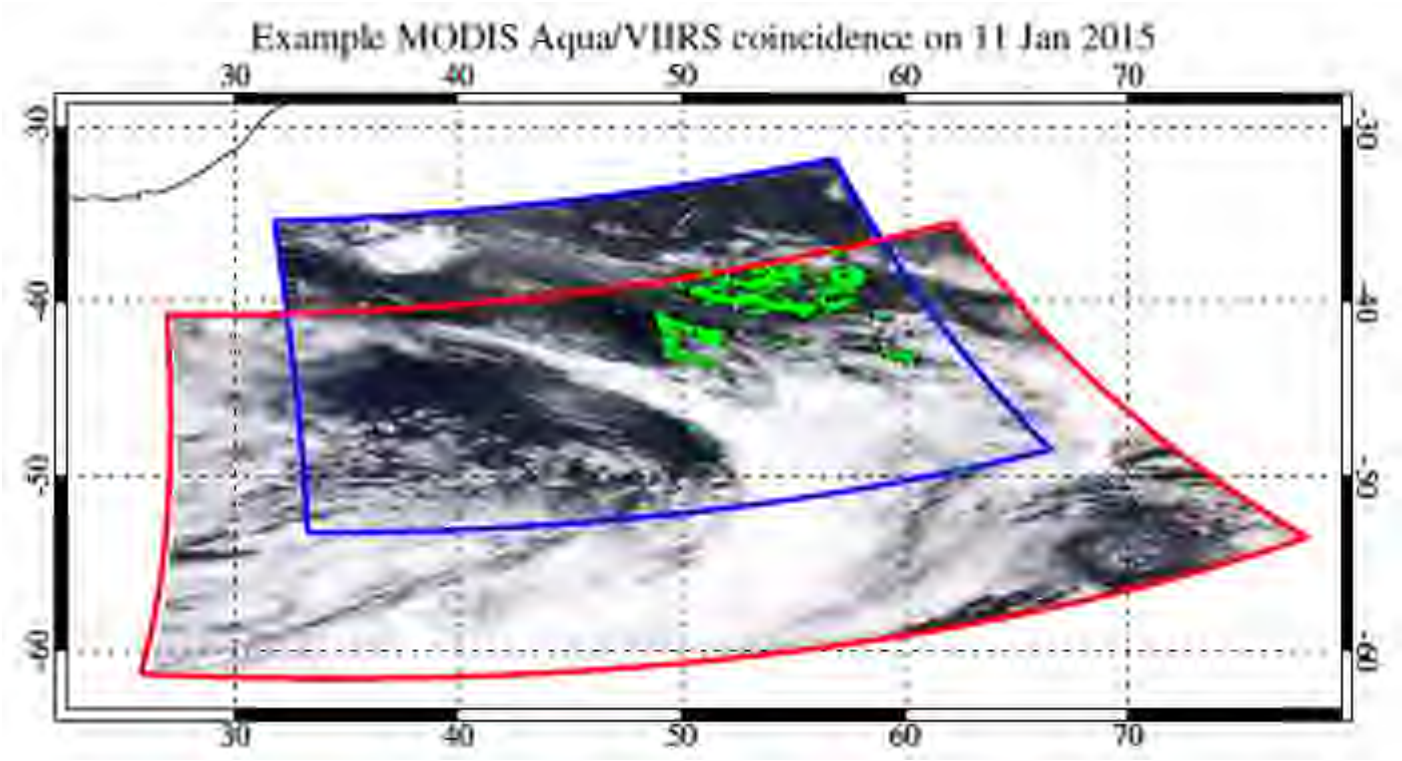


The resulting level of consistency is sufficient for most applications



Sensors can be cross-calibrated to ensure radiometric consistency



Sayer *et al.,* AMTD (in revision, 2016)

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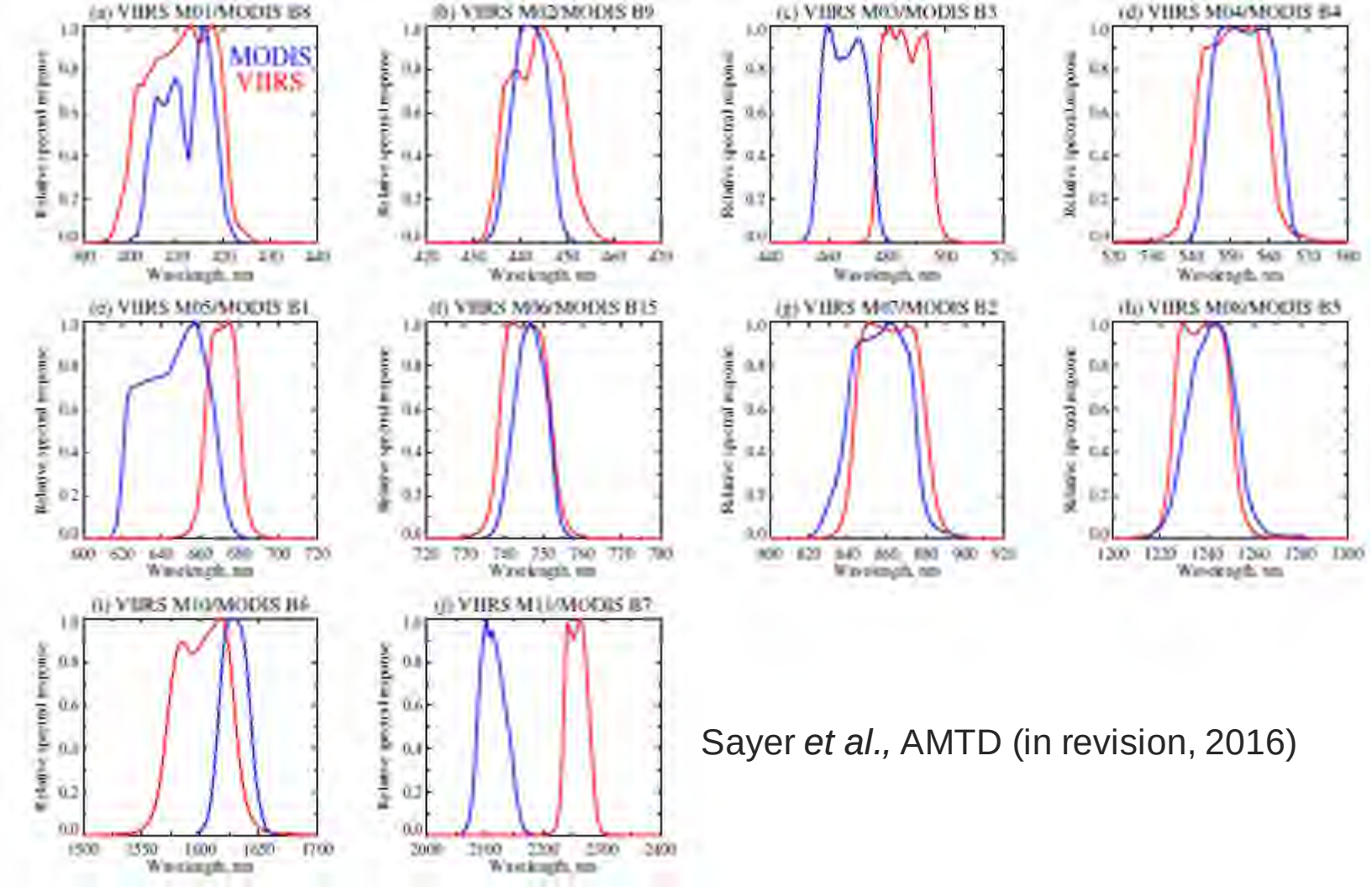

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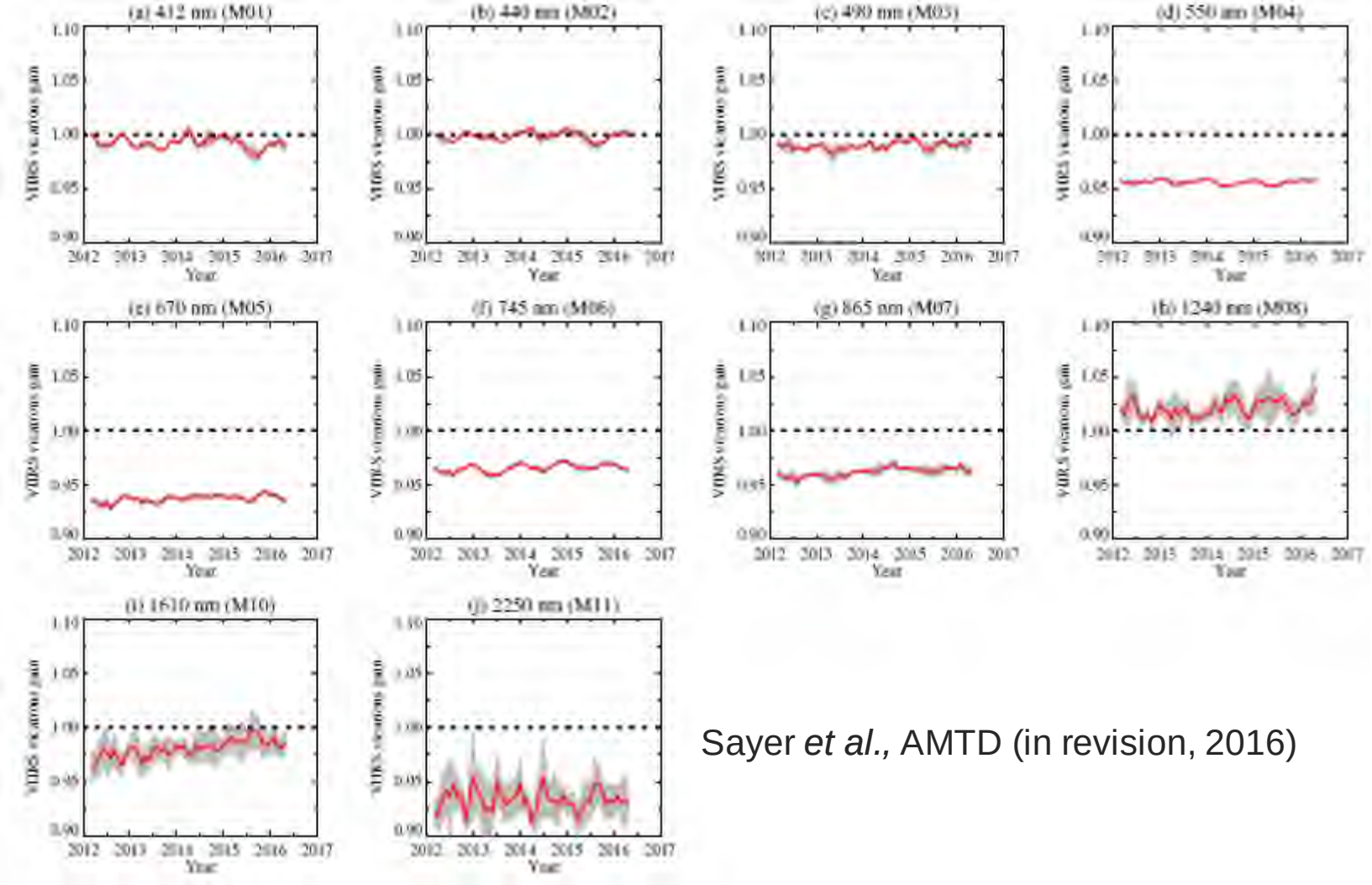

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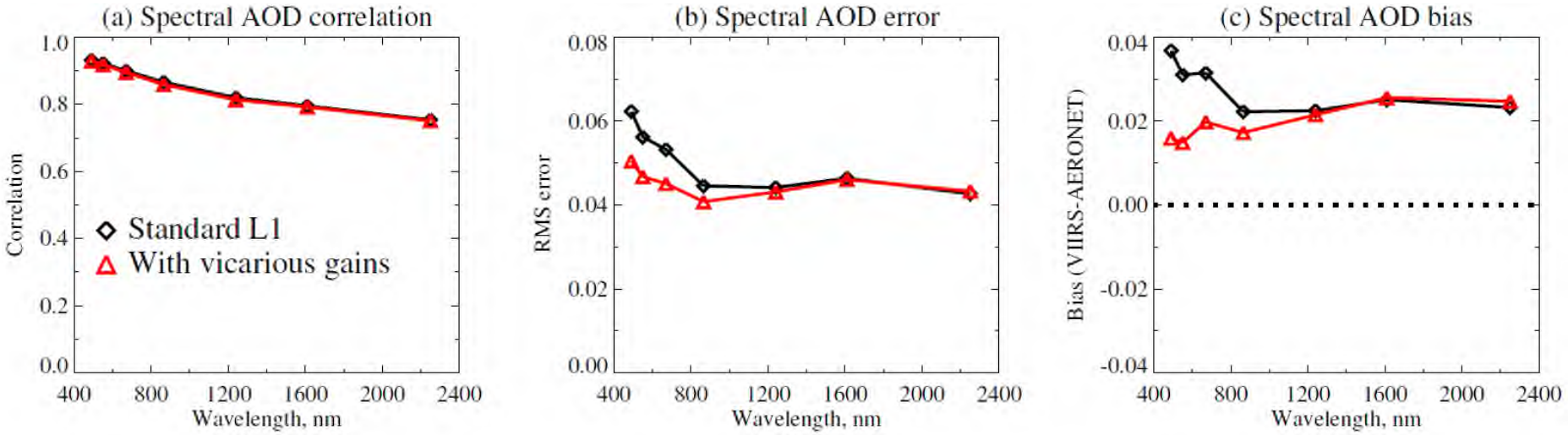
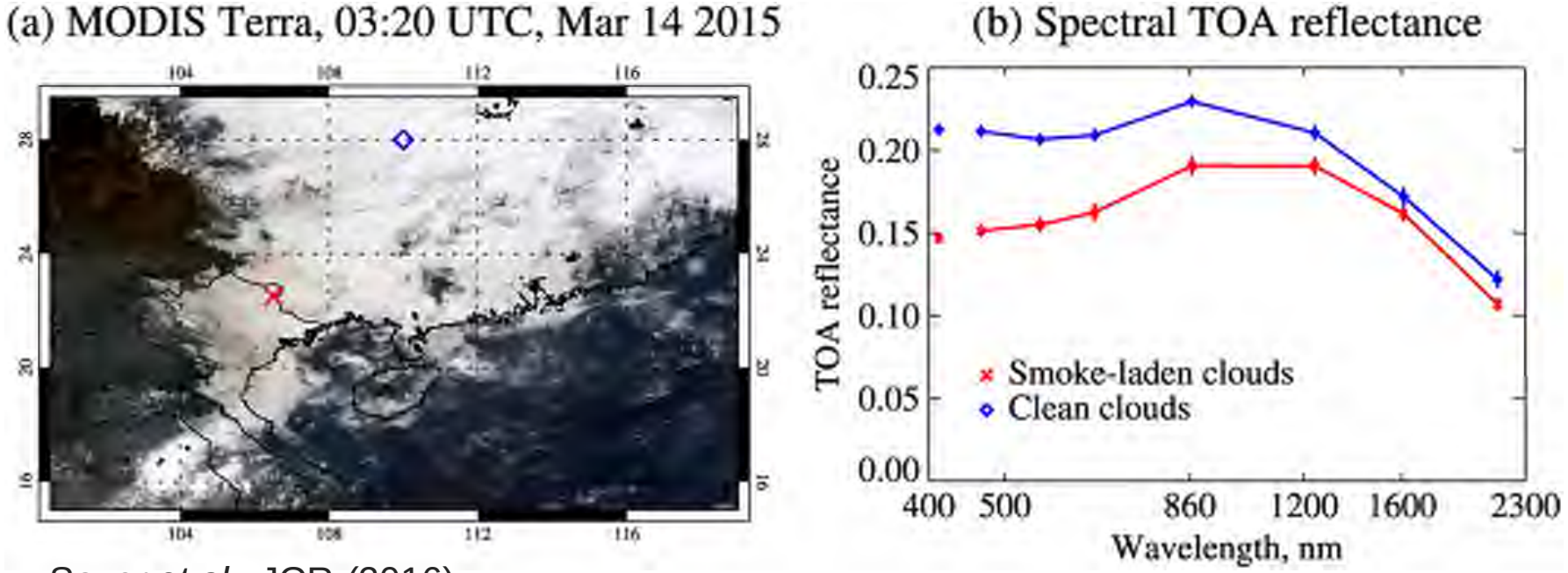


Sayer *et al.,* AMTD (in revision, 2016)

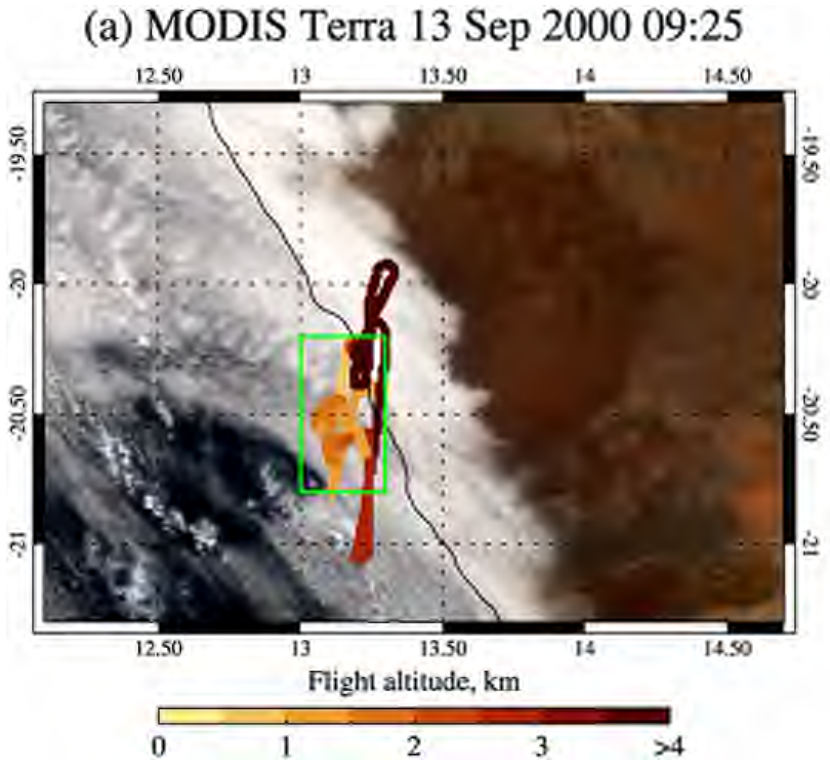
Can we say something about aerosols above clouds?

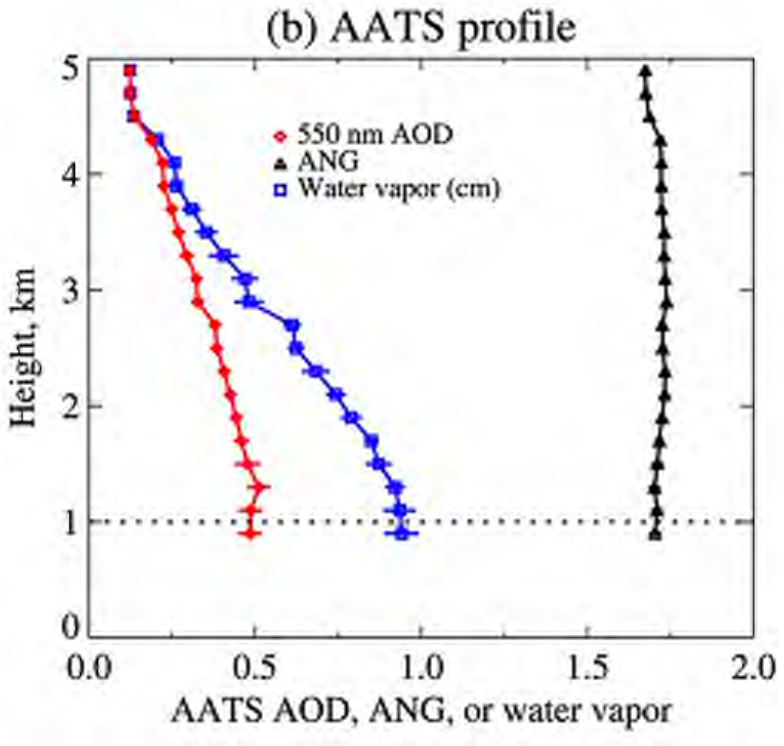


Sayer *et al.,* JGR (2016)

- In most cases, aerosols above a land or water surface *brighten* the scene
- Light-absorbing aerosols above clouds instead *darken* it
- This means that retrievals of cloud properties exhibit *systematic biases* in these cases

Airborne observations are limited, but essential to validate this new approach





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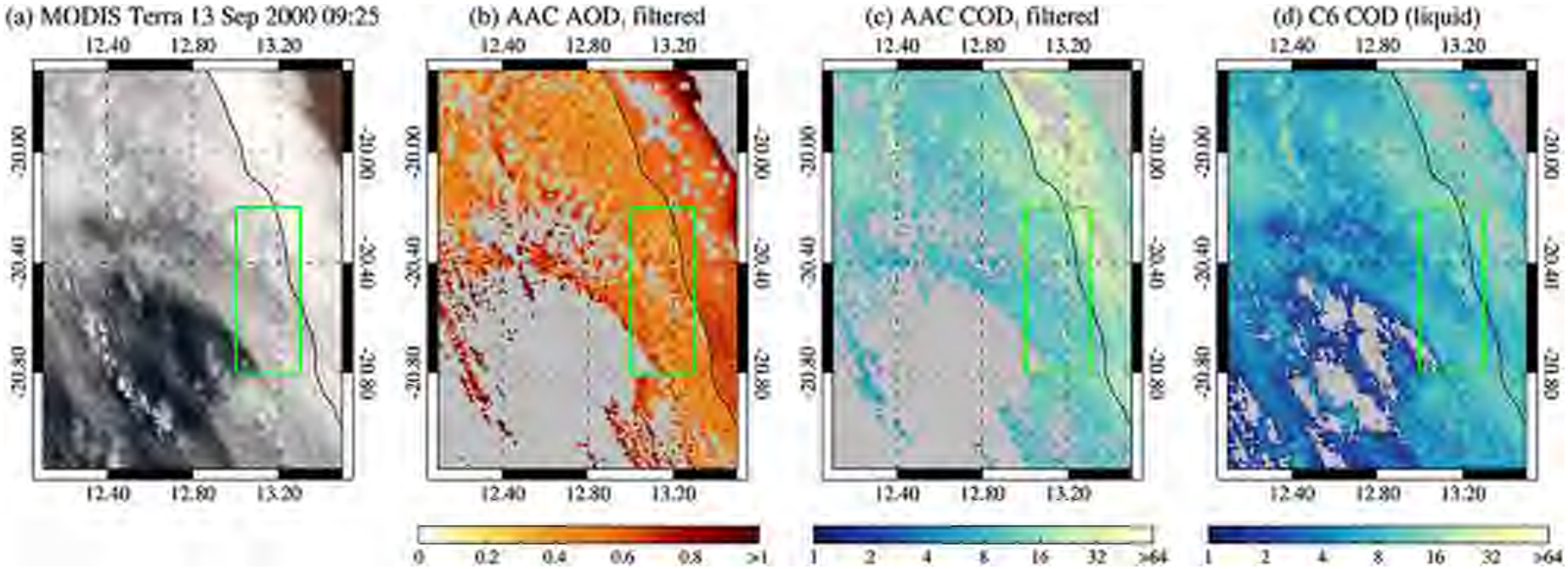

- Airborne estimate of AOD from cloud-top upwards 0.49±0.04
- MODIS-based estimate 0.51±0.10
- Difference between retrieved cloud optical depth and standard (no-aerosol) MODIS cloud product consistent with expectations

There are a lot of opportunities in aerosol science for new researchers

- Instrument development
  - Satellite, ground-based, airborne
  - Field campaigns
- Retrieval algorithm development
  - Physics, statistics, programming, meteorology are all useful
- Laboratory measurements of aerosols
- Interdisciplinary research requires a broad range of expertise
  - Quantitatively linking aerosol loading to air quality and health
  - Ecosystem response to aerosols
  - Radiative effects of aerosols
  - Long-term changes
  - Diurnal variability
  - Hazard detection and avoidance